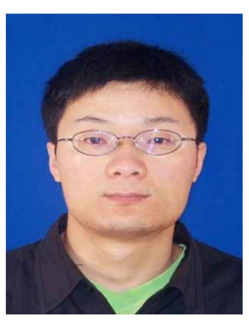

In situ target strength measurements of skipjack tuna *Katsuwonus pelamis* and yellowfin tuna *Thunnus albacares* in the South China Sea

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ABSTRACT

Knowledge of individual target strength (TS, dB) is essential for accurate acoustic assessment of fish abundance. The TS of skipjack tuna *Katsuwonus pelamis* and yellowfin tuna *Thunnus albacares* in the South China Sea was analysed and measured *in situ* using 70 and 120 kHz split-beam echosounders. Biological samples were collected using a light falling-net with valid working depth of 50 m. Mean TS of −50.72 dB at 70 kHz and −54.22 dB at 120 kHz were measured on skipjack tuna composed of 351 mm mean fork length (FL). Mean TS of −36.38 dB at 70 kHz and −38.02 dB at 120 kHz were measured on yellowfin tuna composed of 412 mm mean FL. Skipjack tuna aggregation mainly distributed 30-50 m layer. Yellowfin tuna aggregation mainly distributed 20-30 m layer. *In situ* TS measurements on skipjack tuna and yellowfin tuna provide a useful reference for estimating the body length distribution and abundance around fish aggregating devices. Furthermore TS data obtained in this study on skipjack tuna and yellowfin tuna may be useful for exploring school behavior.

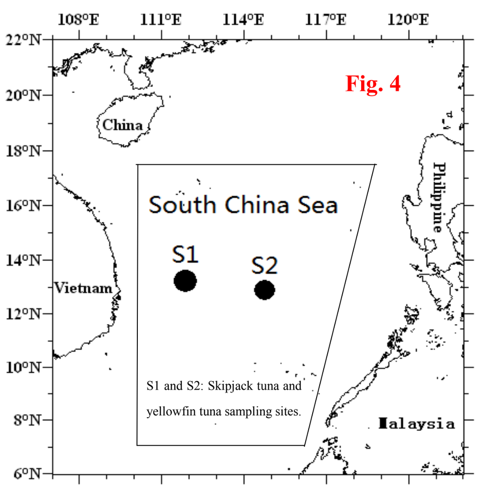
Key words: *Katsuwonus pelamis*, *Thunnus albacares*, fishery acoustics, South China Sea

I. INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) and Yellowfin tuna (*Thunnus albacares*) are both important target species of tuna fisheries around the world. In the South China Sea, skipjack tuna and yellowfin tuna are also abundant and profitable fishing industry. The selective capture of tunas is important for continuable commercial fisheries and stock management. Acoustics are of great importance for study of tuna behavior, species and length composition and estimation of abundance, which is helpful to selective. Information of individual target strength (TS, dB) is essential for the acoustic assessment of skipjack tuna and yellowfin tuna abundance. *In situ* measurements of TS are preferred because, when properly collected, they can be used to characterize mean TS while the fish remain in place and, all being well, unaware of what is going on. Our objective was to evaluate the TS of skipjack tuna and yellowfin tuna.

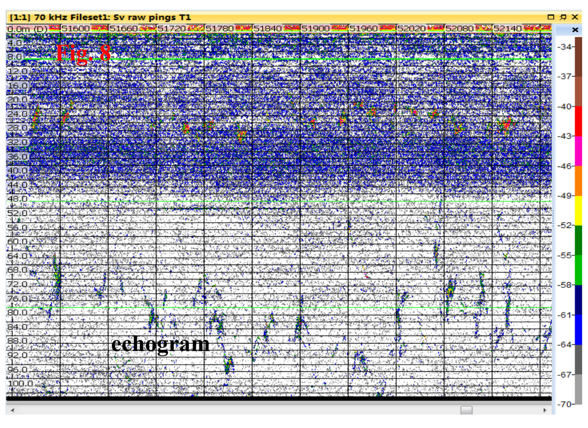
II. Materials and methods

1. Survey time and vessel



A commercial fishing vessel of 43.6 m length, 7.6 m width and 4.1 m draught was employed to carry out the survey (Fig.3). The vessel navigated at day (about 6 knots) and drifted at night. Data of skipjack tuna and yellowfin tuna were collected on 13 and 17 September 2013 respectively in the central and southern South China Sea (Fig. 4).

2. Acoustic data collection



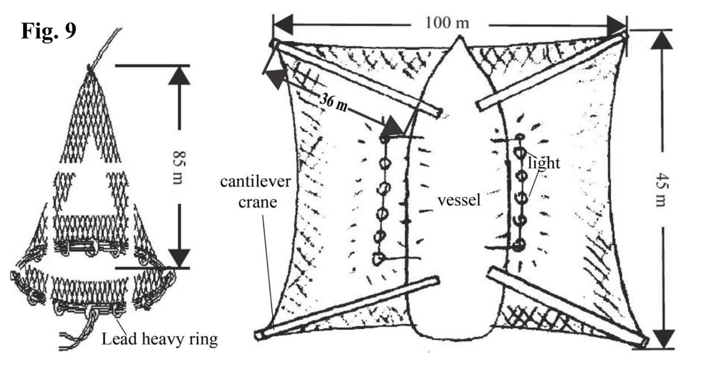
Acoustic data were collected using a Simrad EY60 echosounder with 70 and 120 kHz split-beam transducers (Fig.5), laid horizontally in a stainless steel protective fairwater dome affixed vertically by steel frame mid-ship (Fig.6, 7). The draft of the transducers was 1.5 m. The echosounder was calibrated using the standard procedure (SIMRAD, 2008). Table 1 gives the main settings used during the cruise.

3. Biological samples collection

Table 1. Main settings of the SIMRAD EY 60 echosounder

Setting	70kHz	120 kHz
Transducer type	ES70-7C	ES120-7C
Transducer gain	27.00 dB	27.00 dB
Ping interval	1 s	1 s
Pulse duration	0.512 ms	0.512 ms
Alongship 3 dB beam width	7.00 deg	7.00 deg
Athwartship3 dB beam width	7.00 deg	7.00 deg
Min. echolength	0.8	0.8
Max. echolength	1.8	1.8

Fig. 9



Biological samples were collected using a light falling-net (Fig.9). 230 attracting lamps (1 kw/lamp) were arranged along the sides of vessel in two rows. Net dimensions were 290 m circumference and 85 m stretched length, with a cod-end mesh of 22 mm, and mesh at the net mouth of 52 mm. The maximum working depth of net was 50 m. All biological sampling was undertaken at night.

First fishermen turned on the lamps to lure fish about at 19:00, and then laid a cone-shape (pocket) netting gear below the fishing vessel and stretched the net by four cantilever cranes. When positively phototactic fish were trapped below the net the net was drawn and recovered on deck. Between one and eight net deployments were made on any given evening, with each net deployment and retrieval requiring about 40 minutes.

Upon retrieval, the net was emptied on deck where the catch was sorted, sampled randomly. Species were identified and counted, with standard measurements including fork length (FL) for skipjack tuna and yellowfin tuna, and mantle length (ML) for squid, and body or total length for other fishes (depending on taxon).

4. Acoustic data analysis

Acoustic data were analysed using the Echoview software (version 4.9, Myriax Pty Ltd). the depth and time range for acoustic data included in the analysis was 5–50 m and 20:00–22:00 hrs respectively. The analysis cell was defined as 60 ping × 2 m. In all cases, the averaging process was done in the linear domain (scattering cross-section) and then converted into the logarithmic domain (TS), namely mean $TS=10\log_{10}[(\sigma_1+\sigma_2+\sigma_3+\cdots+\sigma_n)/n]$ (Foote 1987). Acoustic data were correlated with net samples at the same depth and period of time to derive the relationship between TS and FL of skipjack tuna and yellowfin tuna.

III. Results

1. Biological samples

Skipjack tuna aggregation was encountered on 13 September 2013. Table 2 gives detailed information of species composition. Skipjack tuna dominated the catch both in number and weight. The FL of skipjack tuna ranged from 258 to 493 mm, with mean 351 mm and standard deviation (SD) 49 mm.

Table 2. Catches relavant to the single-fish echo-trace data collection of *K. pelamis*

Species		Number		Weight	
Common name	Scientific name	Individuals	%	g	%
Skipjack tuna	*Katsuwonus pelamis*	954	87.9	967302	94.7
Purpleback flying squid	*Sthenoteuthis oualaniensis*	105	9.7	7280	1.3
Yellowfin tuna	*Thunnus albacares*	18	1.7	26598	3.0
Whitetongue jack	*Uraspis helvola*	3	0.3	750	0.1
Jack mackerel	*Acanthocybium solandi*	2	0.2	4850	0.5
Duakyfin bulleye	*Priacanthus hamrur*	1	0.1	170	0.0
Black stingray	*Dasyatis atratus*	1	0.1	2990	0.3
Sargassum triggerfish	*Xanthichthys ringens*	1	0.1	12	0.0

Yellowfin tuna aggregation was encountered on 17 September 2013. Table 3 gives detailed information of species composition. The proportion of yellowfin tuna, ranging 337–412 mm, with mean 412 mm and SD 40 mm, were 9.60% and 54.8% in number and weight in the catch.

Table 3. Catches relavant to the single-fish echo-trace data collection of *T. albacares*

Species		Number		Weight	
Common name	Scientific name	Individuals	%	g	%
Purpleback flying squid	*Sthenoteuthis oualaniensis*	977	86.7	122125	41.9
Yellowfin tuna	*Thunnus albacares*	108	9.6	159588	54.8
Skipjack tuna	*Katsuwonus pelamis*	24	2.1	8371	2.9
Mackerelscad	*Decapterus acarellus*	6	0.5	204	0.1
Blackmouth cardinalfish	*Selar crumenophthalmus*	6	0.5	252	0.1
Bramidae	*Brama japonica*	3	0.3	315	0.1
Snake mackerel	*Thyrsitoides marleyi*	1	0.1	300	0.1
leatherjacket	*Aluterus monoceros*	1	0.1	111	0.0
Finlet crevalle	*Caranx mate*	1	0.1	3	0.0

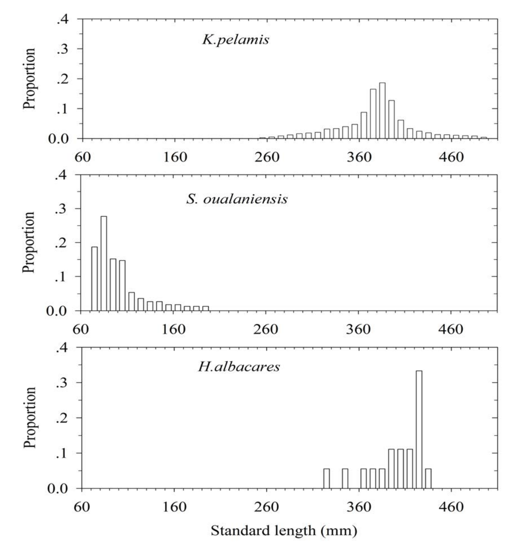


Fig. 12 Length composition of *K.pelamis*, *S.oualaniensis* and *H.albacares* on 13 Sep. 2013.

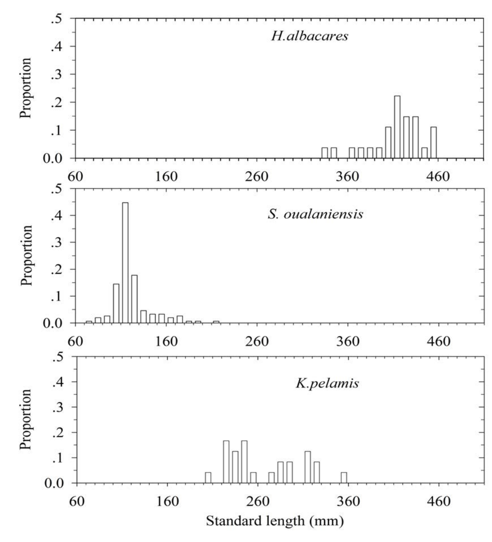
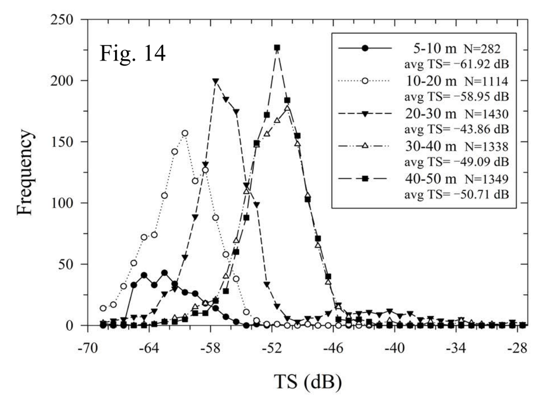
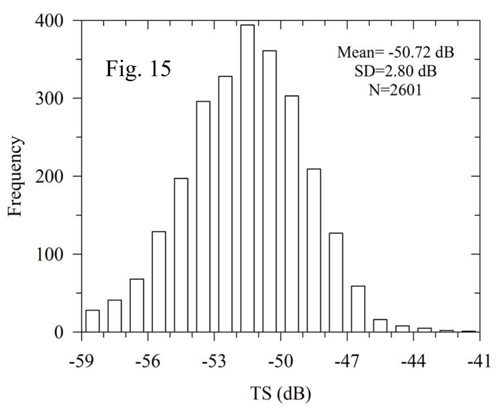


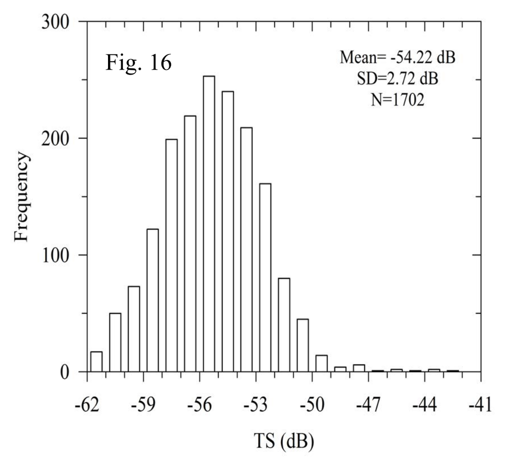
Fig. 13 length composition of *H.albacares*, *S.oualaniensis* and *K.pelamis* on 17 Sep. 2013.

2. TS of skipjack tuna

Fig. 14 depicts the TS distribution of echo data from 5–50 m layer for 70 kHz on 13 September 2013. By comparing standard length distribution with TS distribution and mean TS in different layer, it can be seen that purpleback flying squid dominated in the 10–20 m layer; the 20–30 m layer was the common region of purpleback flying squid, yellowfin tuna and skipjack tuna, and yellowfin tuna also mainly distributed in that layer. In order to avoid further contamination attributable to other organisms, only data in the 30–50 m layer were used to estimate the *in situ* TS of skipjack tuna. Figure 15 and Figure 16 depict the TS distribution of selected skipjack tuna single-fish echo traces for 70 and 120 kHz respectively.



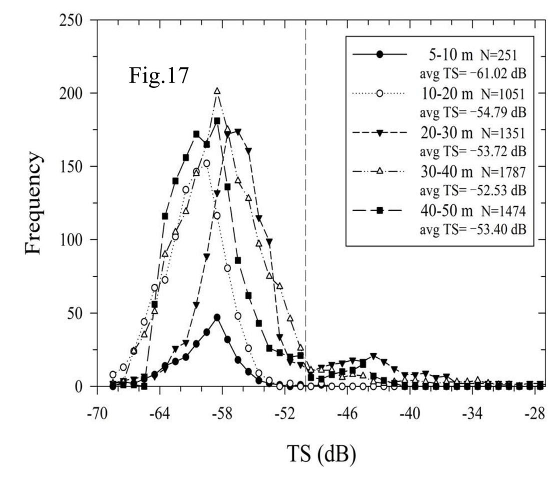


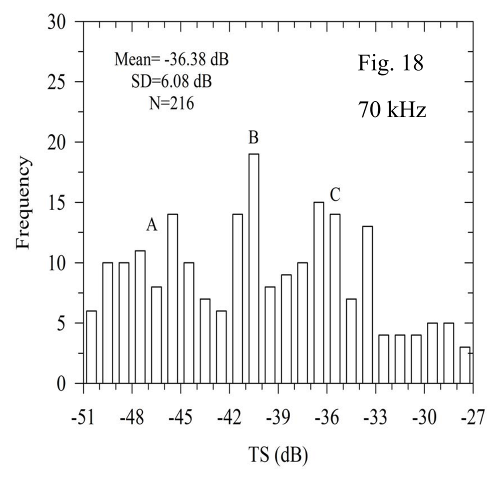


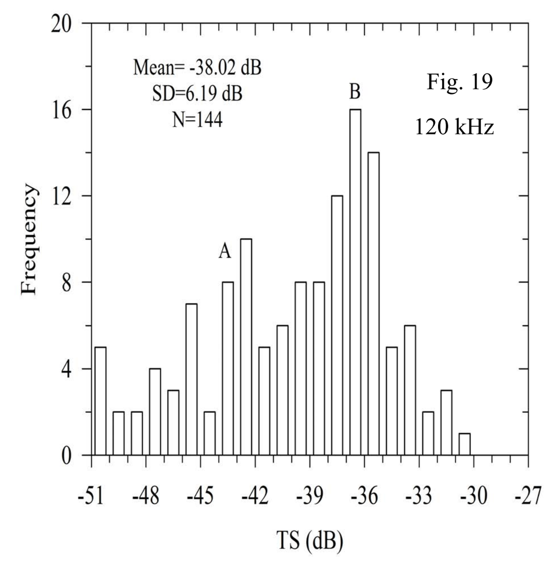
We excluded targets echoes smaller than −59 dB at 70 kHz and targets echoes smaller than −62 dB at 120 kHz to remove contributions from other week scatterers. We also excluded targets larger than −41 dB to remove contributions from yellowfin tuna. We obtained that mean TS of −50.72 dB (95% SD: 2.92) at 70 kHz and −54.22 dB (95% SD: 2.71) at 120 kHz on skipjack tuna composed mainly of 351 mm mean fork length by comparing "average TS" with "average FL of skipjack tuna caught in the net.

3. TS of yellowfin tuna

Figure 17 shows the TS distribution of echo data from 5–50 m layer for 70 kHz on 17 September 2013. That changes in TS distribution with depth reflected a change in fish species composition with depth. In the 5–10 m and 10–20 m layer, one mode of *in situ* TS was found respectively approximating to -59 dB and -60 dB, which reflected the dominant presence of purpleback flying squid. In the 20–30 m, 30–40 and 40–50 m layer, two modes of *in situ* TS were found respectively which obviously implied that common presence of purpleback flying squid and yellowfin tuna. Echoes of yellowfin tuna could be discriminated though purpleback flying squid still dominated. The *in situ* TS data in the 20–50 m layer were used to estimate TS of yellowfin tuna. The frequency distribution of TS of selected yellowfin tuna single-fish echo traces for 70 and 120 kHz respectively are shown in Figure 18 and Figure 19.







For 70 kHz, the mode (A) in Figure 10 may be shifted from big-sized fish (400-440 mm). The modes (B, C) correspond the dominant size fish, and reflect the inherent variability of TS. For 120 kHz, a major mode (B) and a minor mode (A) in the *in situ* TS were observed (Figure 11). The mode (A) in Figure 11 may be shifted from big-sized fish (400-440 mm). We excluded targets echoes smaller than −51 dB to remove contributions from weak scatterers. We obtained that mean TS of −36.38 dB at 70 kHz and −38.02 dB at 120 kHz on yellowfin tuna composed mainly of 412 mm mean fork length.

IV. Comparison with other studies

A few good measurements have been carried out on the TS data of tuna using different methods (Table 4). In out study, skipjack tuna were present in the 30–50 m layer. Matsumoto *et al*. (2014) studied behavior of skipjack tuna associated with a drifting FAD and concluded that swimming depth of skipjack tuna was usually shallower than 50 m during nighttime.

Table 4. Published standardize TS as a function of the FL compared with the results of the standardized TS of tuna obtained in this study

Source	Condition	Frequency (kHz)	Slope	Intercept	FL (cm)	Species
This study	*in situ*	70	20	−81.60	35*	*Katsuwonus pelamis*
This study	*in situ*	120	20	−85.08	35*	*Katsuwonus pelamis*
This study	*in situ*	70	20	−68.64	41*	*Thunnus albacare*
This study	*in situ*	120	20	−70.28	41*	*Thunnus albacare*
Bertrand *et al*., 1999	*in situ*	38	20	−70.36	60	*Thunnus albacare*
Bertrand *et a*l, 1999	*in situ*	38	20	−72.08	90	*Thunnus albacare*
Bertrand *et al*, 1999	*in situ*	38	20	−71.07	108	*Thunnus albacare*
Bertrand *et al*, 1999	*in situ*	38	20	−67.68	120	*Thunnus albacare*
Lu *et al*, 2011	*in situ*	200	20	−72.12	42*	*Thunnus albacare*
Lu *et al*, 2011	live (*ex situ*)	200	20	−73.69	42*	*Thunnus albacare*

*mean value

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Representative Publications:

Zhang J, *et al*. Hydroacoustic studies on the commercially important squid *Sthenoteuthis oualaniensis* in the South China Sea[J]. Fis. Res, 2015, 169;

Zhang J, *et al*. Acoustic target strength measurement of *Epinephelus awoara* and *Stephanolepis cirrhifer* in the South China Sea[J]. J. Appl. Ichthyo., 2013, 29;

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